Week 2

Day	9:00 - 10:15	10:30 - 11:45	1:30 - 2:45	3:00 - 5:00
Mon	Matching Techniques	Synchrotron Radiation	Overview of Facilities	Lab: Matching/Insertions
Tues	Sensitivity Analyses	A Design Study: SSC	*Homework Review & Discussion*	Lab: Design and Analysis
Wed	Space Charge Effects	Instrumentation	*Homework Review & Discussion*	Lab: Design and Analysis
Thur	Transverse Coupling	Lattice Issues for the Future	**Review Session**	Lab: *Finish Labs*
Fri	**Wrap Up 9:00-9:30 a.m.**	**Final Exam 10:00 a.m.-noon**		

Monday

- Matching -- putting it together
  - beta function matching
    - cells; insertions
  - dispersion matching
  - Modularity and Intelligibility
- Other off-momentum considerations (if time)
- Synchrotron Radiation

Optical Design

Components and Techniques

- First Key Question: What is the purpose of the accelerator / beamline?
  - sets requirements on particle energy, luminosity/brilliance, beam size, acceleration rate, particle targeting rate, ...
  - ...which sets requirements for B, B′, ...

Next Questions:

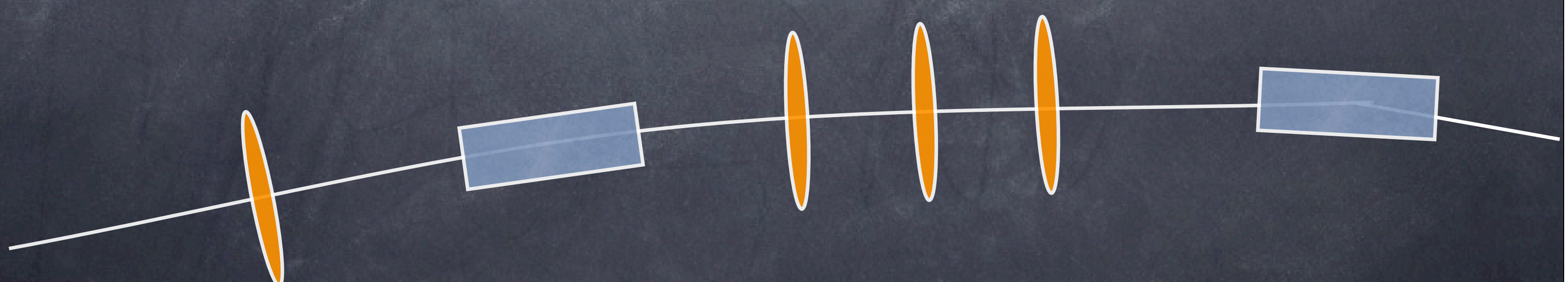
- key parameters?   aperture, final focus, momentum acceptance, momentum manipulations, high intensity, ...
- special requirements?   slow spill, e^- stripping, diagnostic section(s), collimators/halo removal, beam cooling, ...
  - also, # users/experiments: 10-100? (LS); 1-10? (HEP);   1-2? (medical), etc.
- choice(s) of technology?   max. field strengths, straight sections lengths, apertures, ...

Questions, cont'd...

- system constraints?
  - geometrical -- existing tunnel(s), beam line direction/orientation, accomodation of surface features, geological, ...
  - components -- existing magnets, existing power supplies, diagnostics, accelerating cavities, ... COST! ...
- source(s) of particles?
  - charge, injection energy, emittances, ...

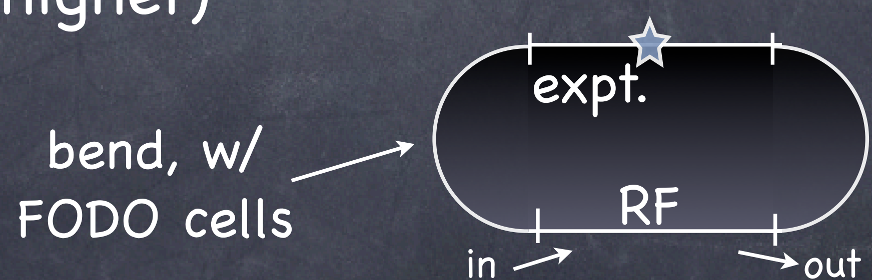
Ex: Light Source

- Synchrotron Radiation due to bending (next lecture) -- want low dispersion function in the bending magnets --> produces smaller equilibrium emittances
- Typically, lower energy (~1-10 GeV) electrons; many users!
    - thus, can tolerate lower "packing fraction":
        - $2\pi\rho/C \lesssim 50\%$



Ex: HEP Synchrotron

- Here, typically very high energy, few experiments (though still MANY users!)
  - need lots of bending, perhaps less need for free space in the system
  - may look like mostly FODO cells, with space for RF accelerating cavities, injection/extraction, etc.
  - here, typically much larger packing fraction (70-80% or higher)



Beta Function Control

- Matched Insertions
- Collins Straight Section
- Quarter-wave Transformer
- Interaction Region / Final Focus

Dispersion Control

- Achromatic Bends
- Dispersion Suppressor
- Imaginary Transition Energy
- Transition Jump
- Bunch Compression

Homework due Tuesday

- Problem Set 3 -- #6
- Problem Set 4 -- # 1
- Problem Set 5 -- #10 (1.8 T is wrong; calculate the necessary value!)
- Problem Set 5 -- #11   (use rho = 750 m, and R = 1000 m)

Synchrotron Radiation

- Radiation of accelerated charge
- Energy loss per turn; per meter; per radian
- Damping of oscillations
- Quantum Excitation of Betatron Oscillations
- Equilibrium beam emittances
- Energy Spectrum

Homework due Tuesday

- Problem Set 3 -- #6
- Problem Set 4 -- # 1 (find tune shift in vertical plane: betax ~ betay= 30m)
- Problem Set 5 -- #10 (1.8 T is wrong; calculate the necessary value!)
- Problem Set 5 -- #11   (use rho = 750 m, and R = 1000 m)

Electron Facilities

- Electron Synchrotrons
  - High Energy Physics
    - CESR, LEP,
    - PEP II, KEKb, ...
  - Light Sources
    - NSLS, ALS, APS, ...
- Electron Linacs
  - Medical Accelerators
  - SLAC SLC, CEBAF, ...
  - Future -- TESLA FEL, ILC?

Luminosity, Brightness

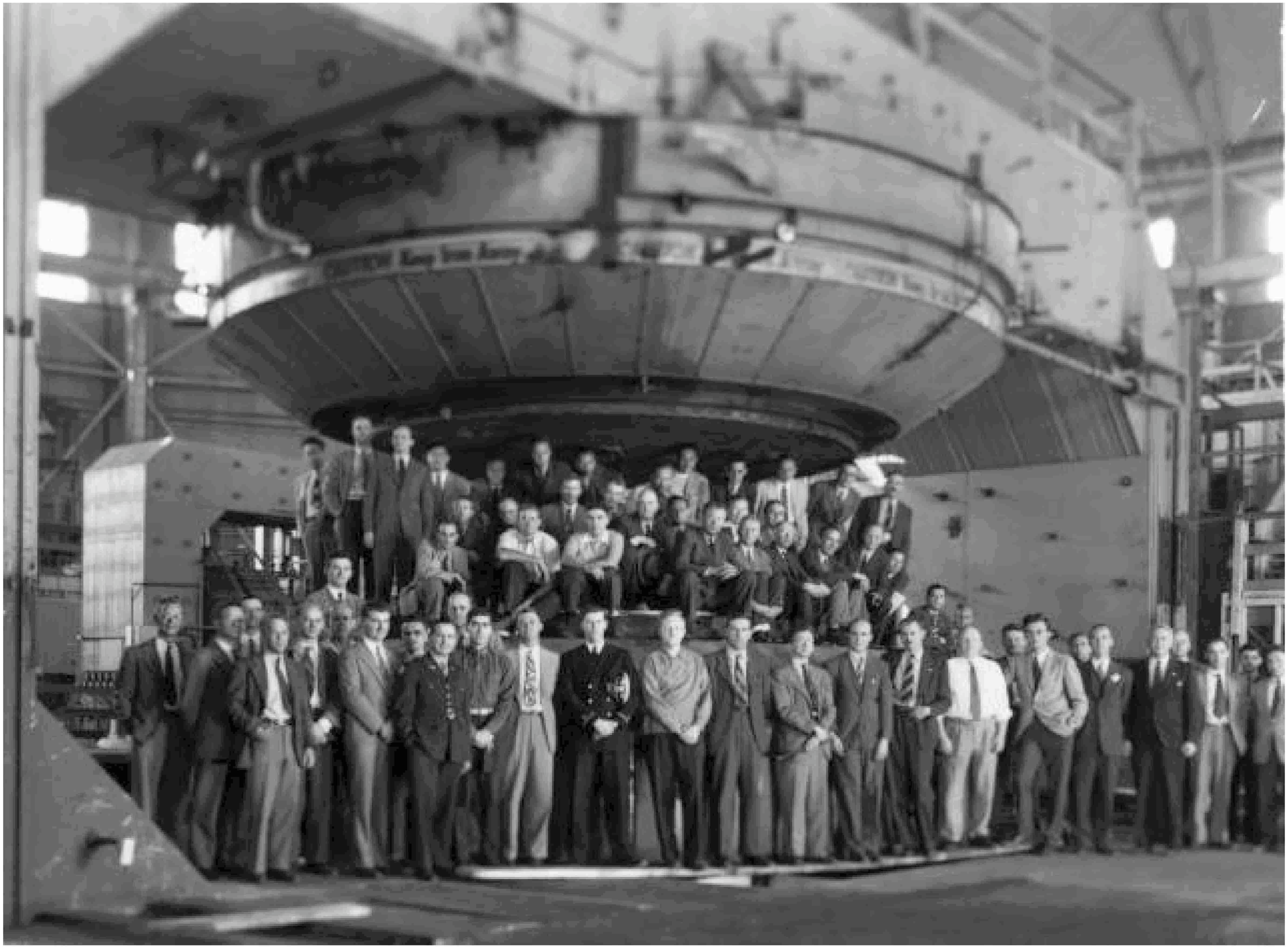
FODO vs. Comb Fcn vs. other lattice options

wigglers, undulators, FEL

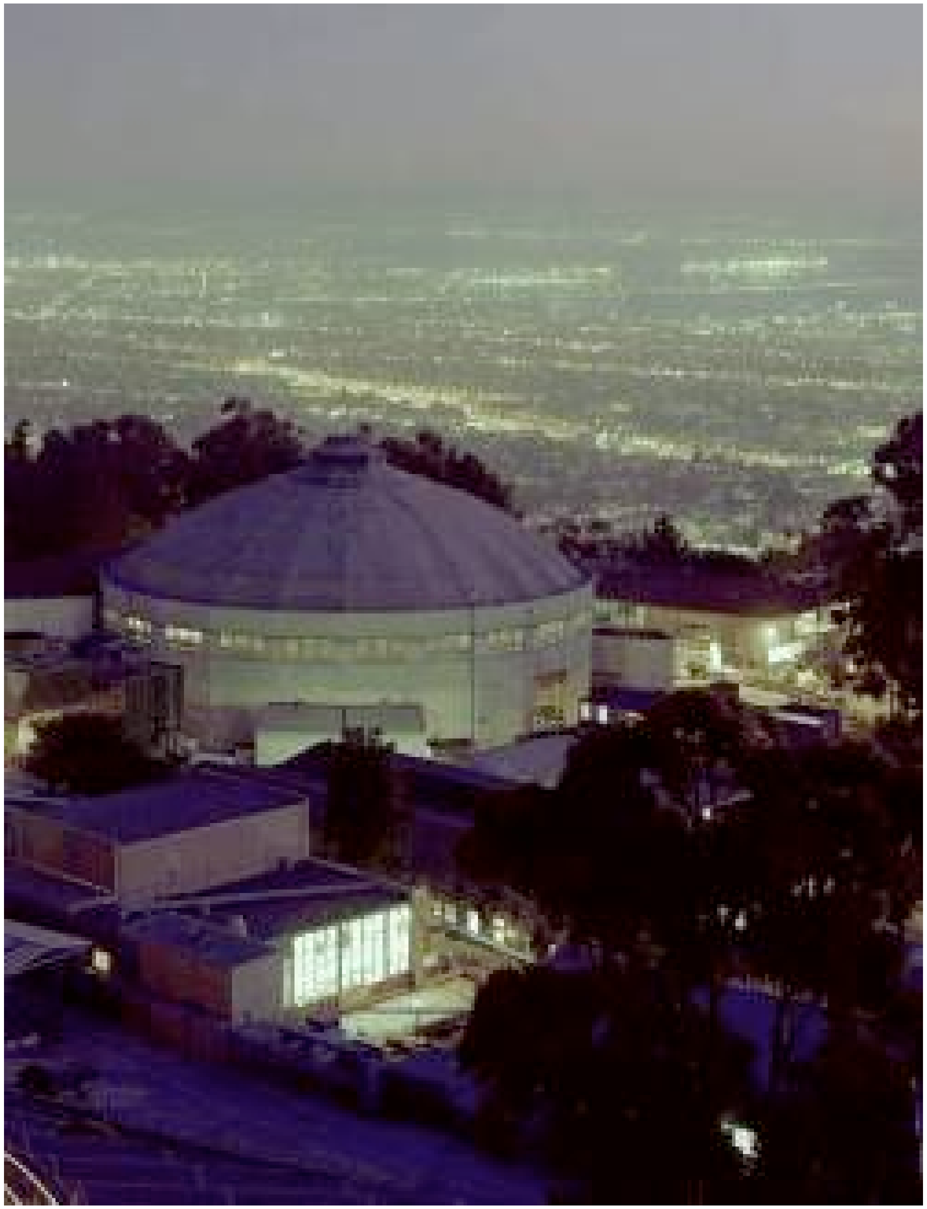
"Generations" of LS's

Cornell University -- CESR

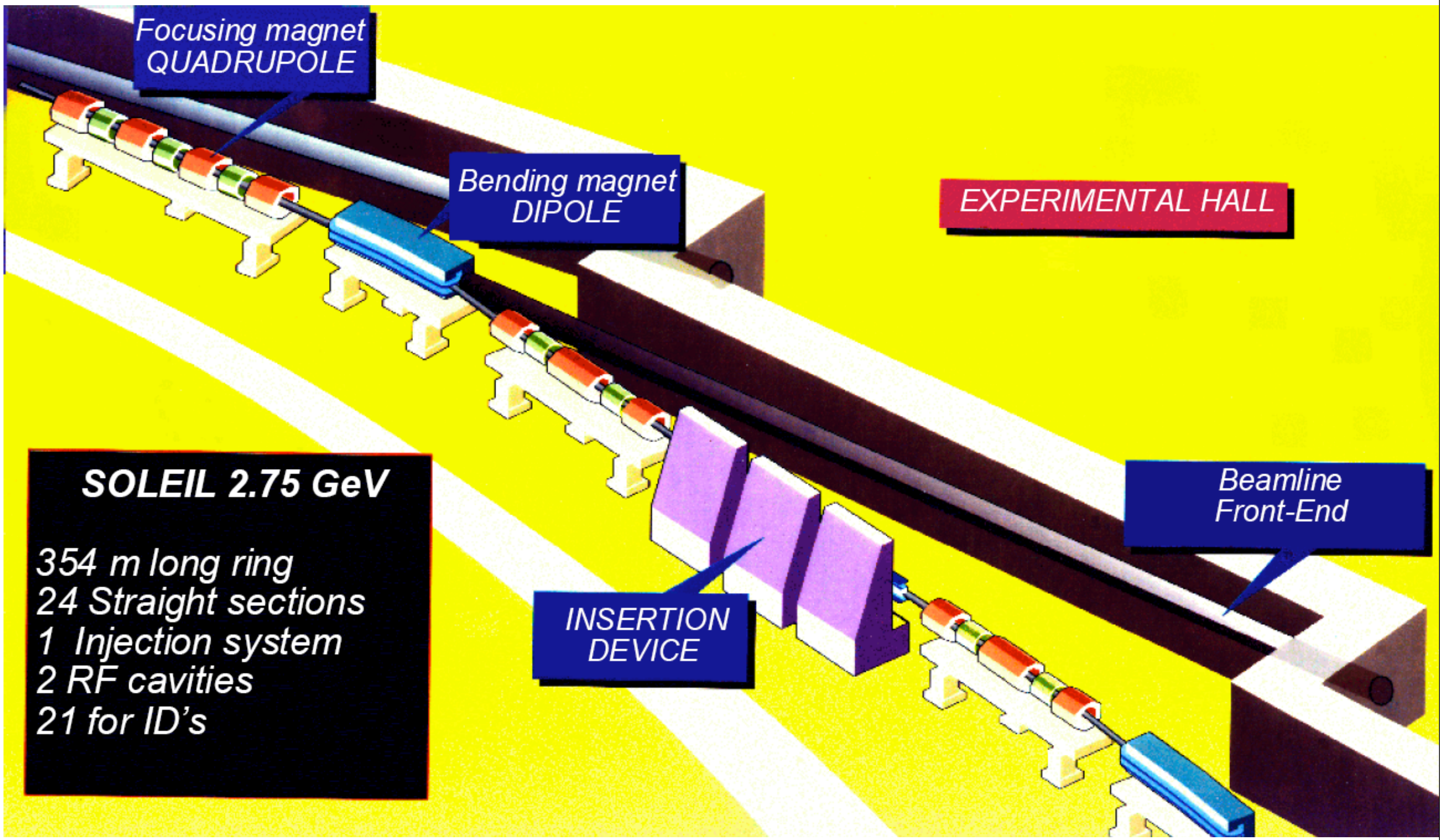
184-inch Cyclotron, Berkeley -- 1940's



Now, a light source -- ALS



A typical lattice for a storage ring



Light Source Lattices

- Chasmin-Green
- Triple-bend achromats
- Minimum emittance lattice
- Bunch compression
- Coherent SR
- Insertions for wigglers/undulators

Chasmann-Green cell

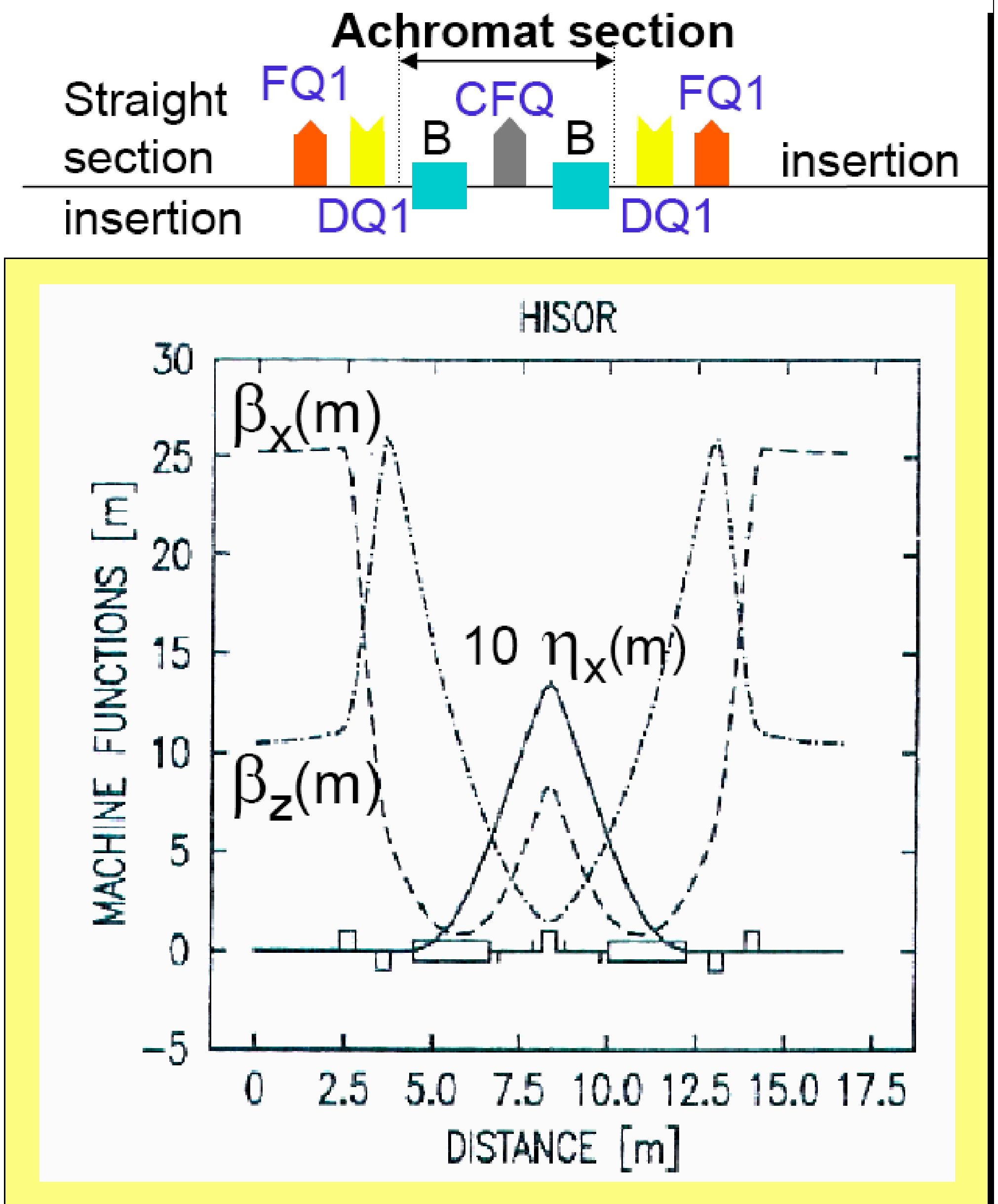
- Double bend achromat with unique central quadrupole
- Achromatic condition is assured by tuning the central quadrupole
- Minimum emittance with a quadrupole doublet in either side of the bends
- The required focal length of the quad is given by

$$f = \frac{1}{2}(L_{\mathrm{drift}} + \frac{1}{2}L_{\mathrm{bend}})$$

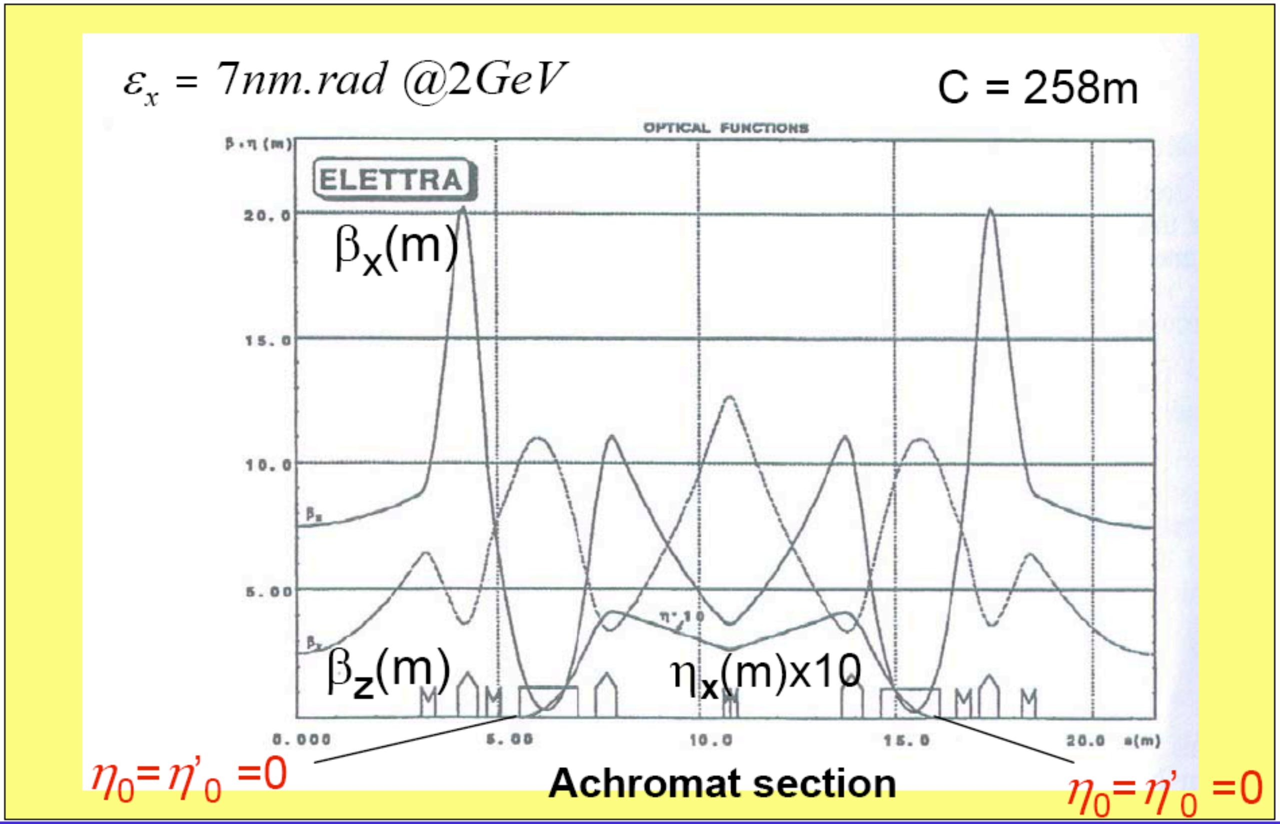
and the dispersion

$$D_c = (L_{\mathrm{drift}} + \frac{1}{2}L_{\mathrm{bend}})\theta$$

- Disadvantage the limited tunability and reduced space

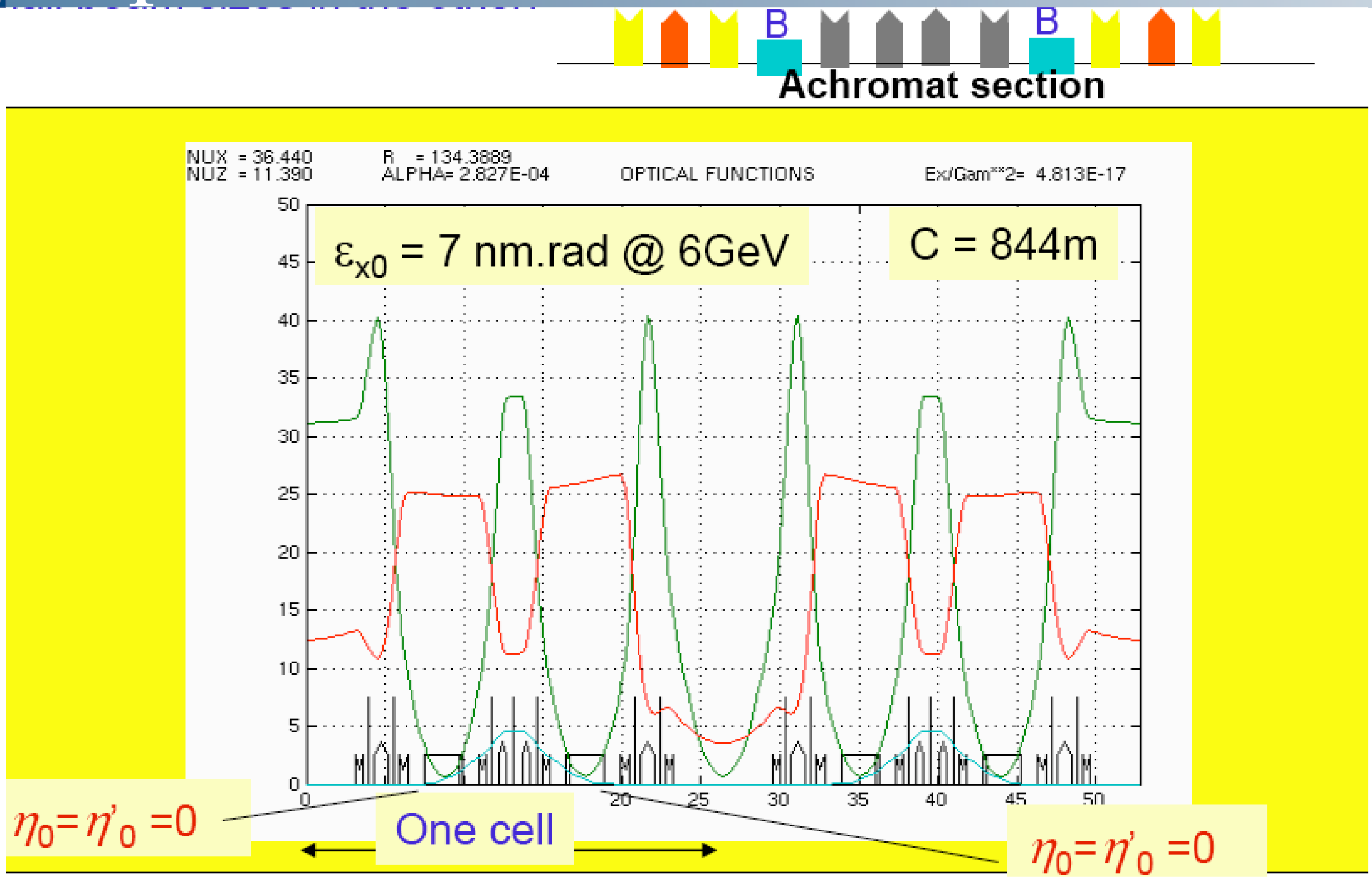


DBA with triplet



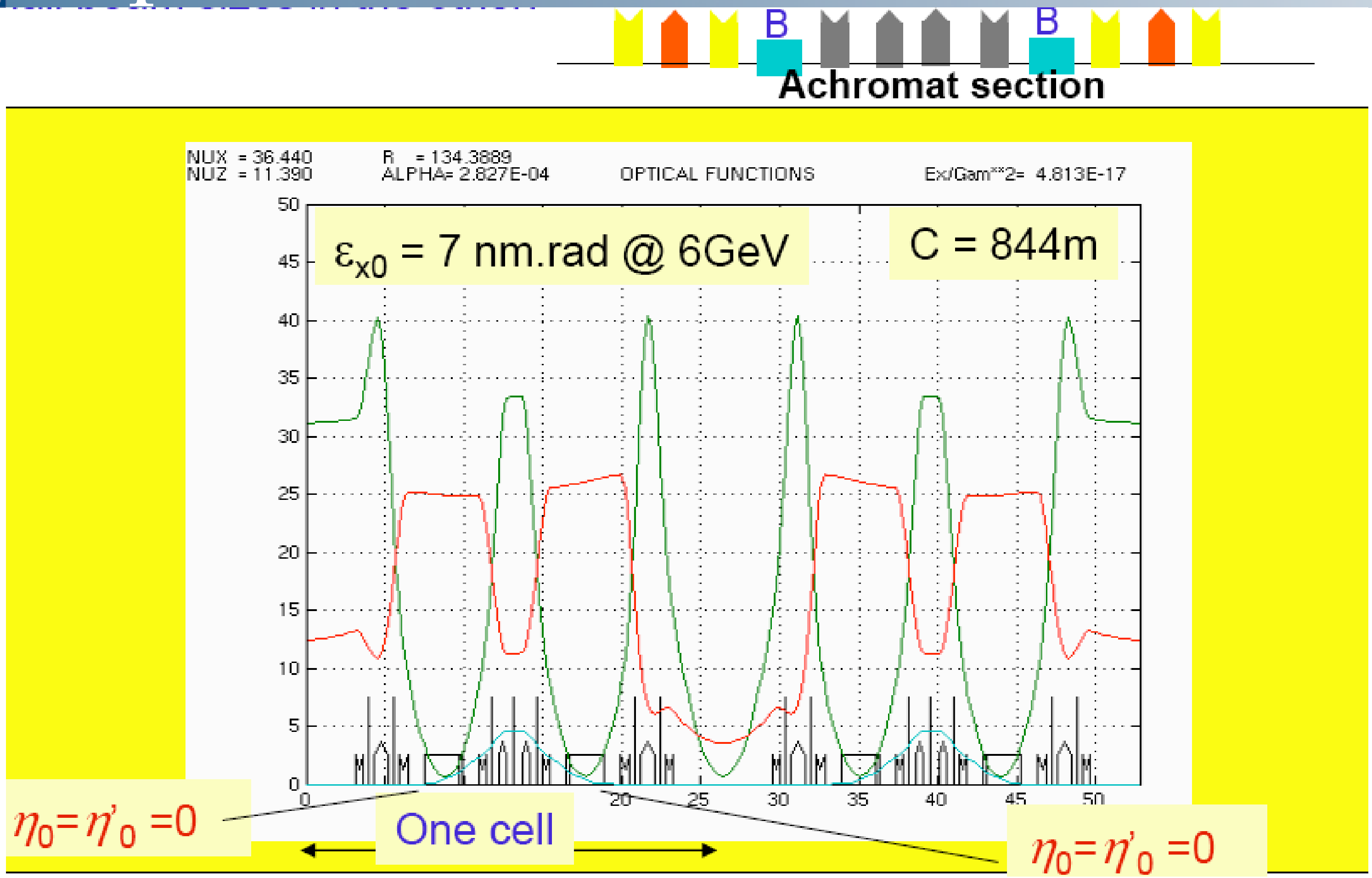
- Central triplet between the two bends and two triplets in the straight section to achieve the minimum emittance and achromatic condition
- Elettra (Trieste) uses this lattice achieving almost the absolute minimum emittance for an achromat
- Disadvantage the increased space in between the bends

Expanded DBA



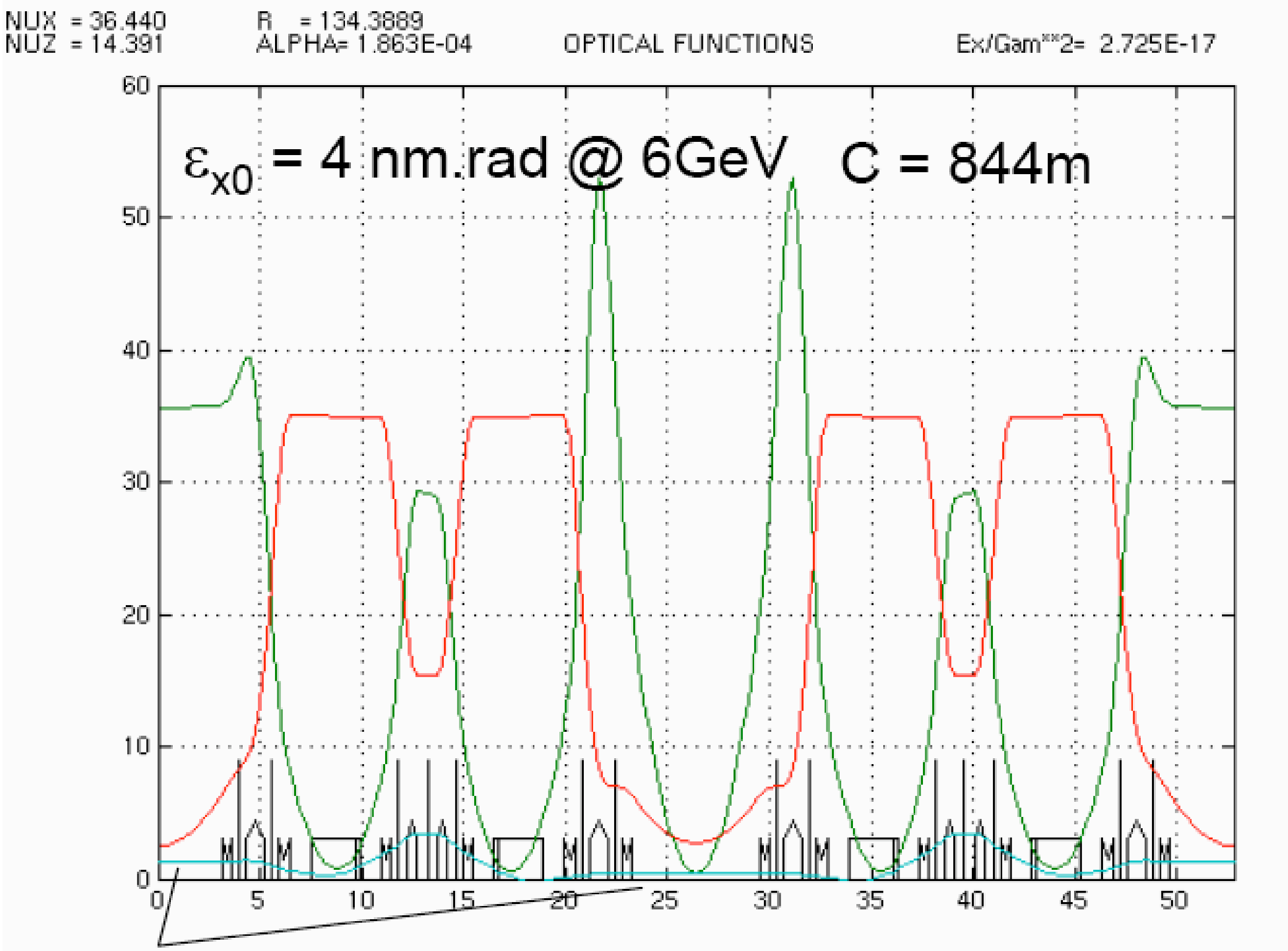
- Original lattice of ESRF storage ring, with 4 quadrupoles in between the bends
- Alternating moderate and low beta in intertions

Expanded DBA II



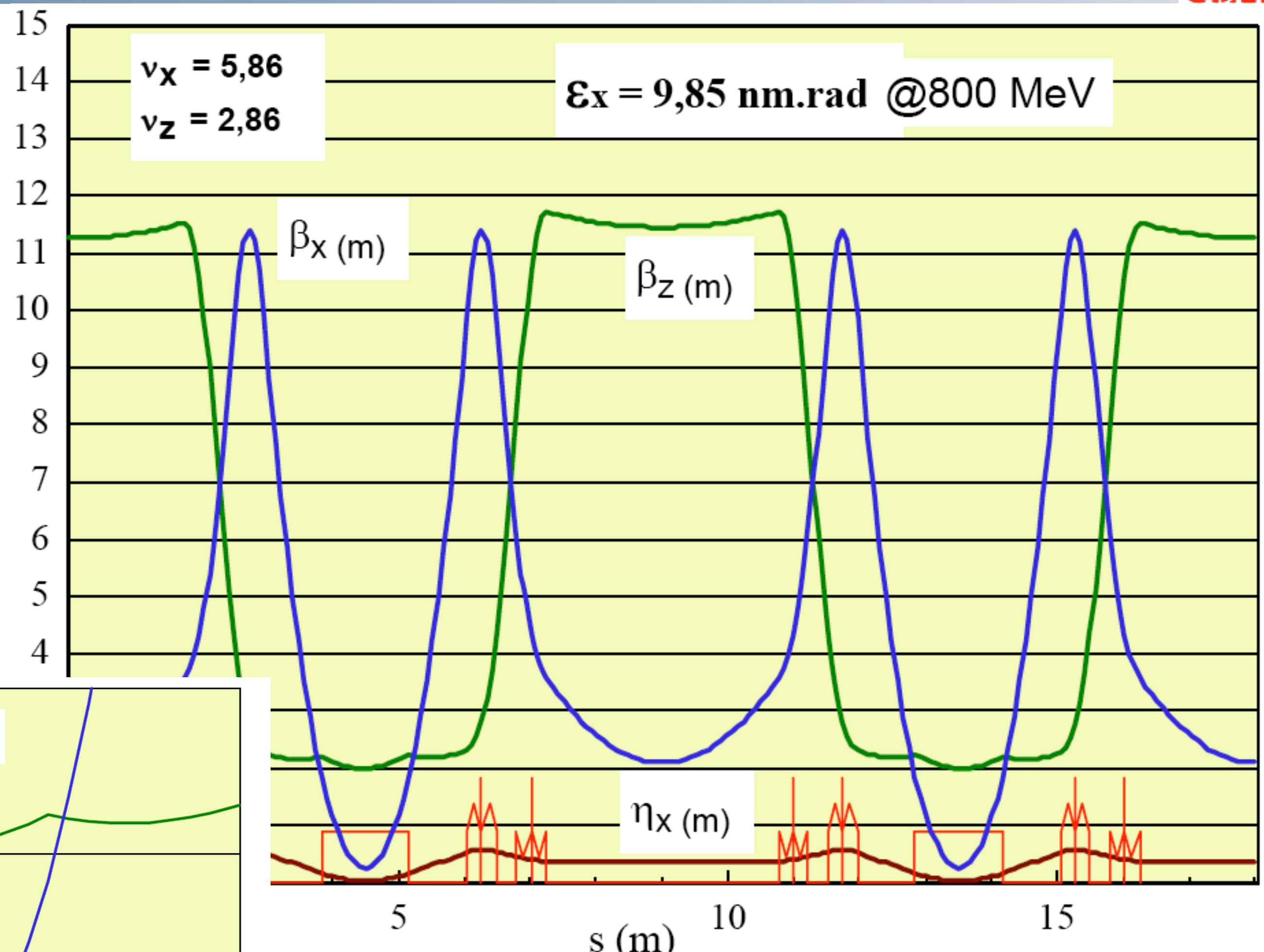
- Original lattice of ESRF storage ring, with 4 quadrupoles in between the bends
- Alternating moderate and low beta in insertions

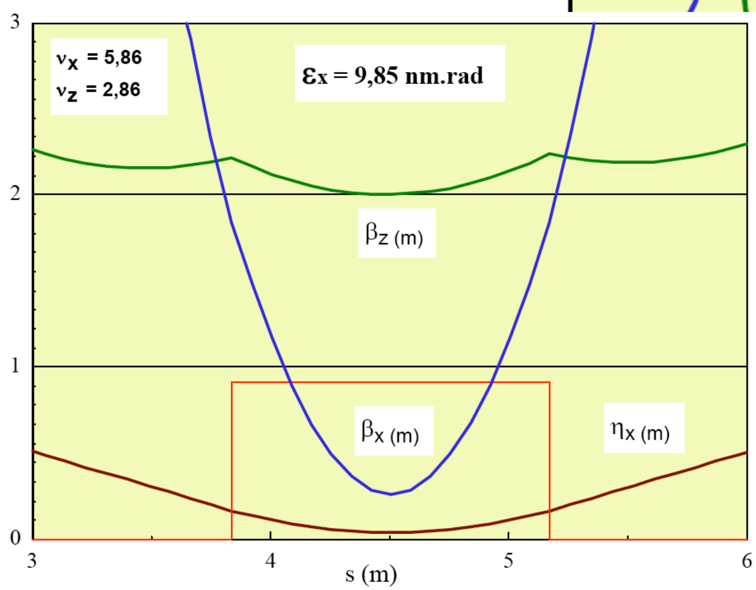
General double bend structure



- Reduce emittance by allowing dispersion in the straight sections
- ESRF reduced emittance almost halved the emittance achieved

Theoretical minimum emittance optics

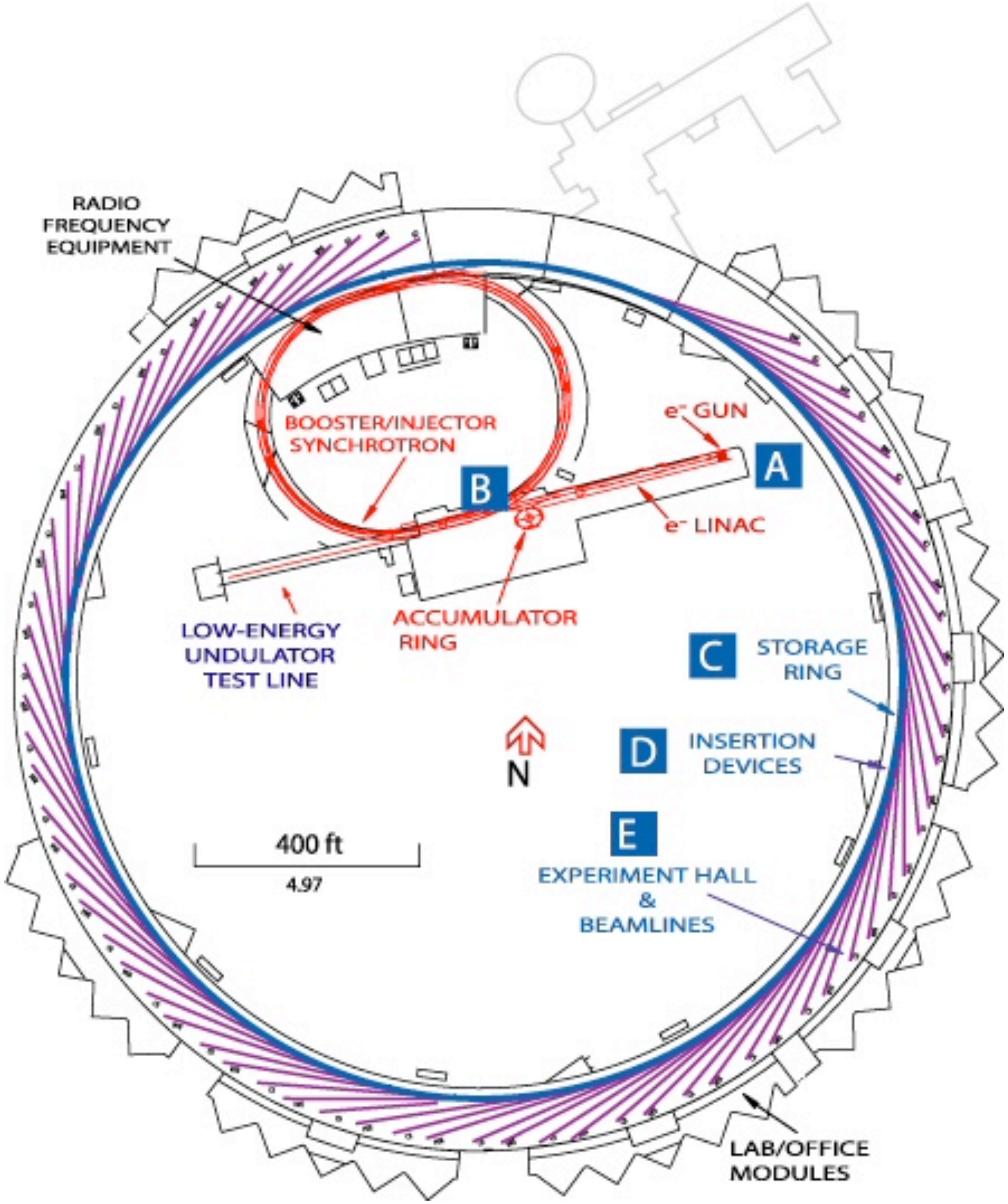




- Old Super-Aco ring could operate in a theoretical minimum emittance optics
- Structure mostly used in damping rings

Advanced Photon Source (APS) -- Argonne National Laboratory

The APS



RADIO
FREQUENCY
EQUIPMENT
BOOSTER/INJECTOR
SYNCHROTRON
e⁻ GUN
A
B
e⁻ LINAC
LOW-ENERGY
UNDULATOR
TEST LINE
ACCUMULATOR
RING
C
STORAGE
RING
N
D
INSERTION
DEVICES
400 ft
4.97
E
EXPERIMENT HALL
&
BEAMLINES
LAB/OFFICE
MODULES

Undulator at the APS

Stanford Linear Accelerator Center

LEP, Geneva -- 1990's

Proton Facilities

- Proton Synchrotrons -- FT
  - CERN, Fermilab
    - SpS, MR, Tevatron
- Hadron Colliders
  - Sp(pbar)S, Tevatron
  - RHIC
- Hybrids -- HERA
- High Intensity
  - PSR, SNS, AGS, MI, ...
- Future -- LHC; VLHC? Proton Driver, nu Source, ..

Luminosity, Power

Collider vs. Fixed Target

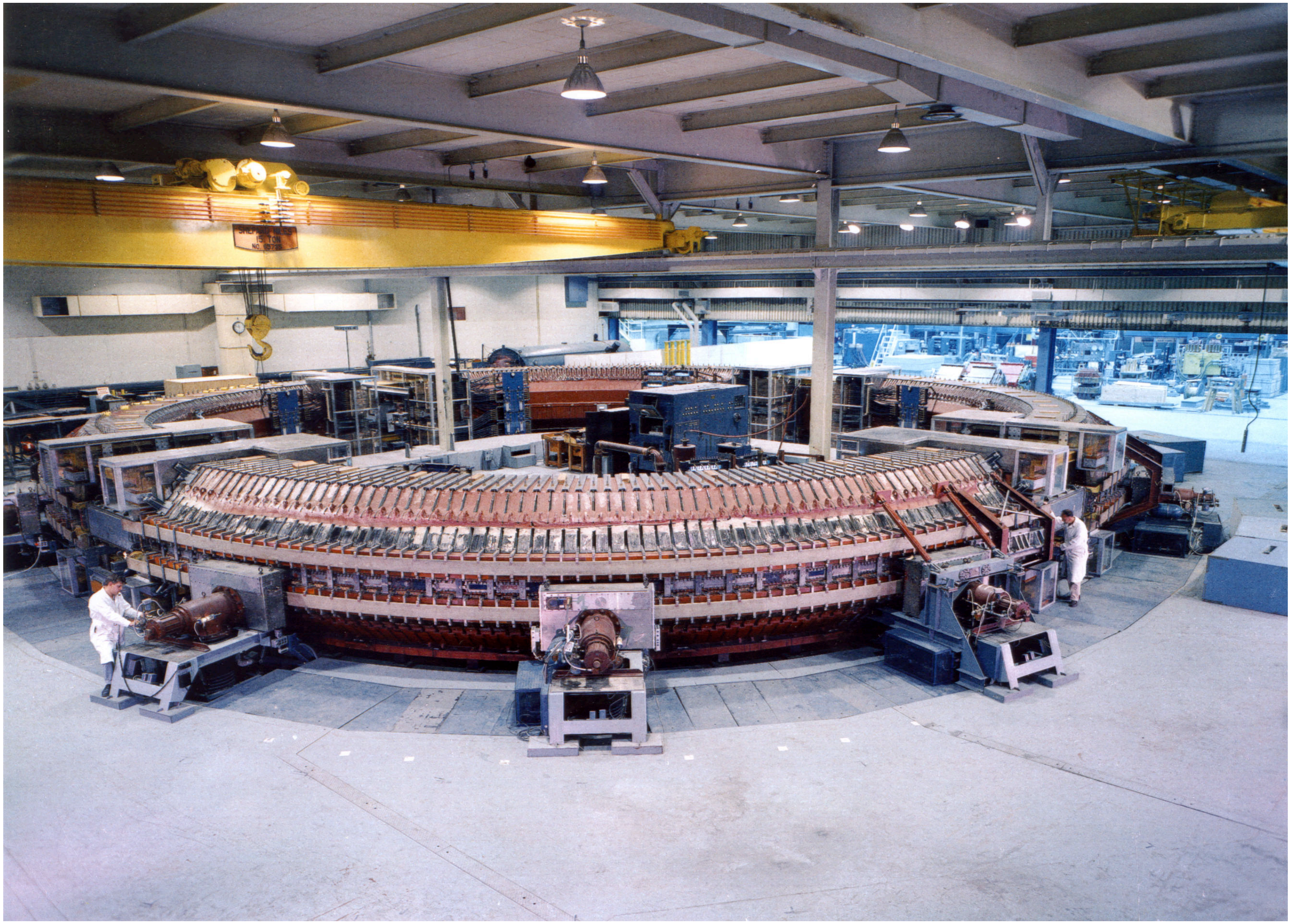
Interaction Regions

Emittance preservation

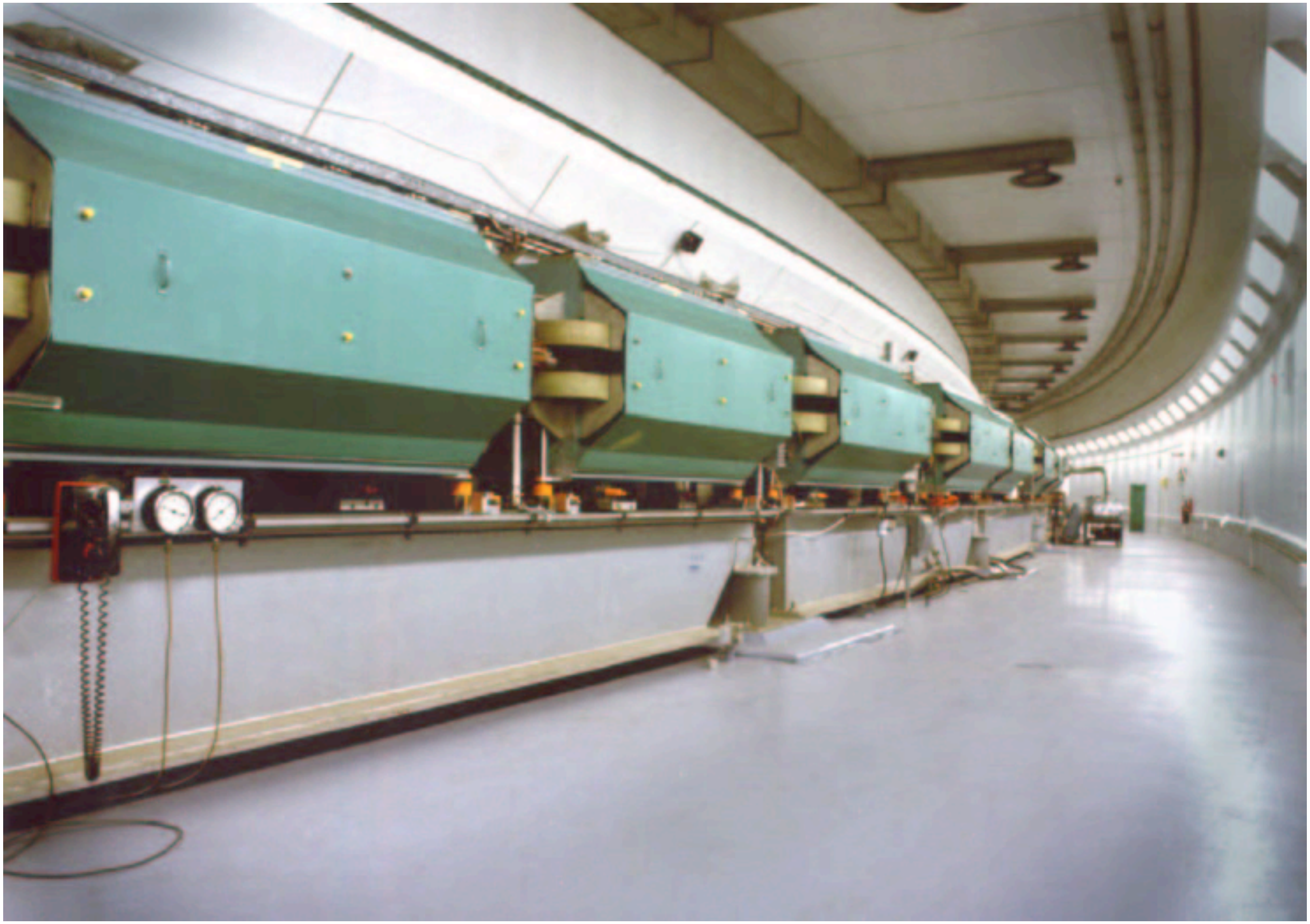
Antiproton production

Heavy Ions, polarized protons, ...

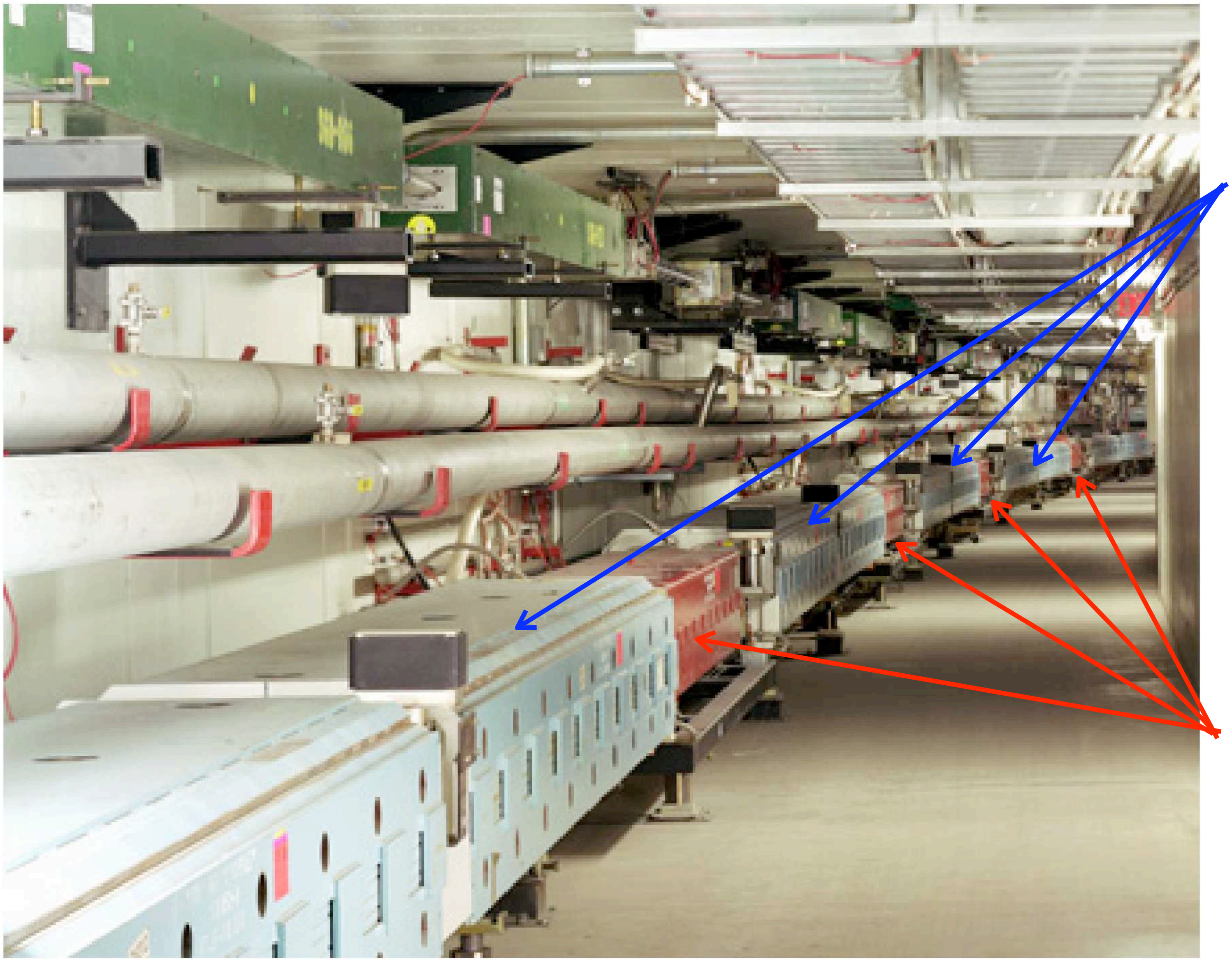
Cosmotron, Brookhaven -- 1950's



AGS, Brookhaven -- 1960's



Example: FNAL Main Injector



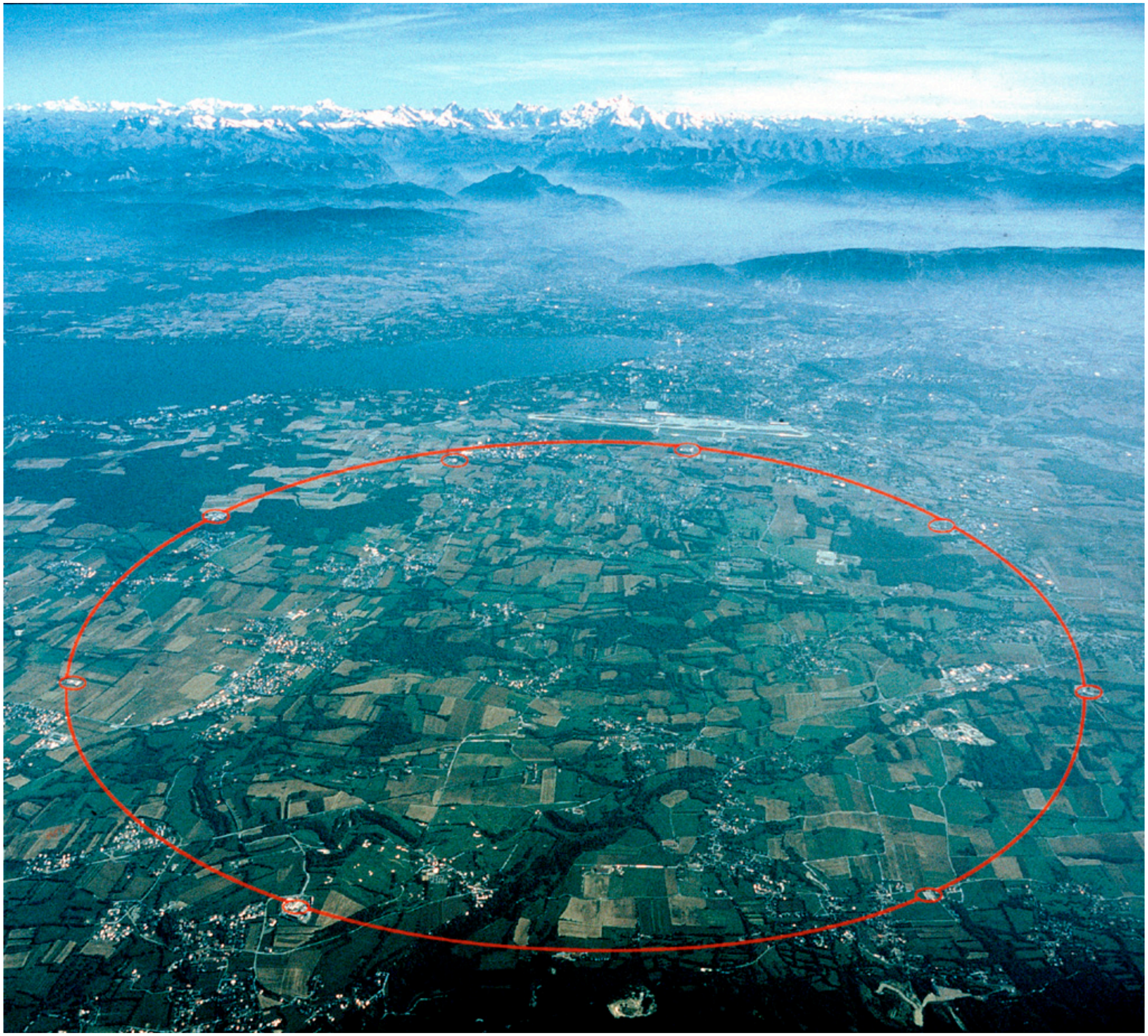
Tevatron, Batavia -- 1980’s

Relativistic Heavy Ion Collider
Brookhaven -- 2000's

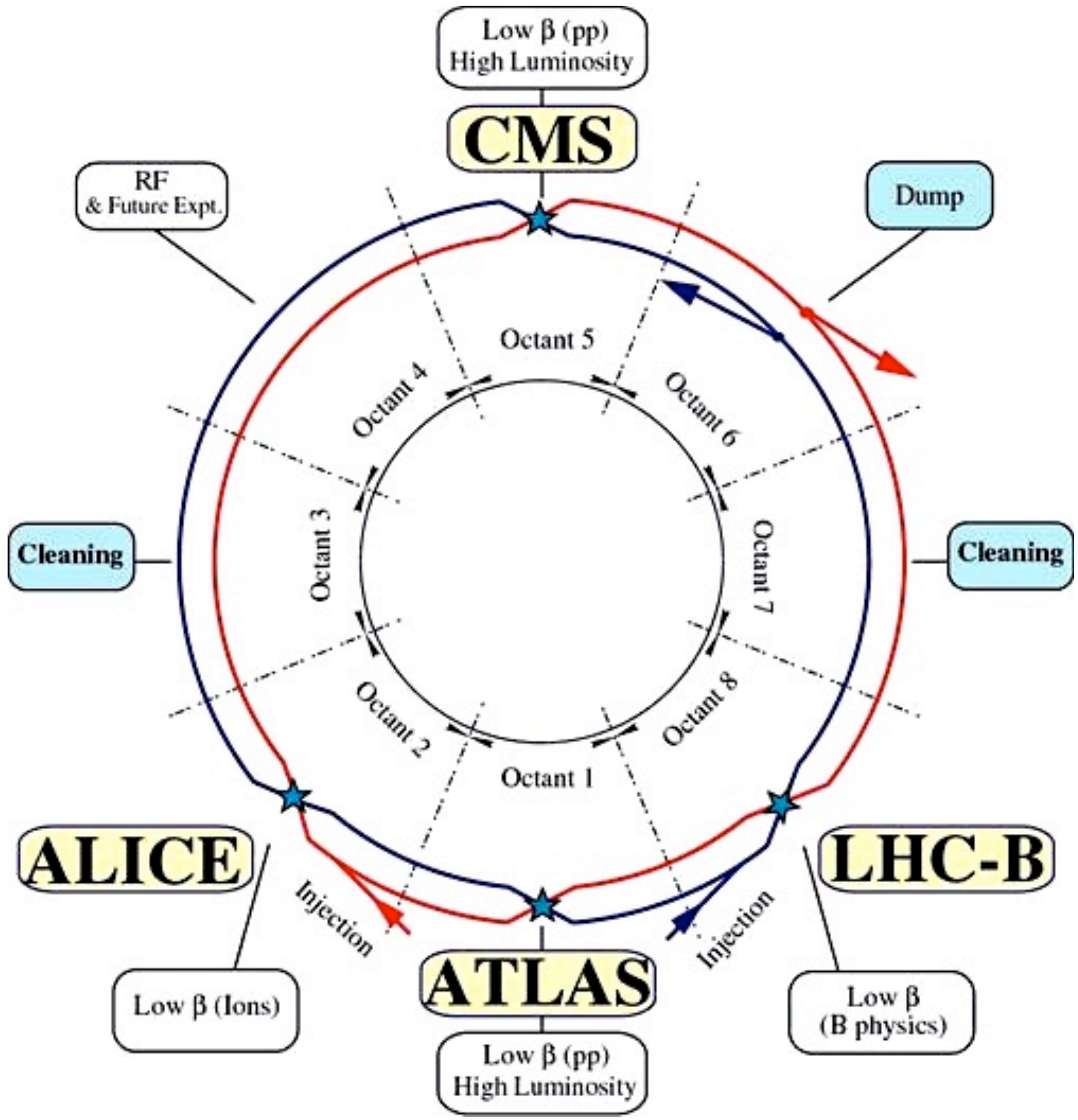
Brookhaven National Lab

Fermilab

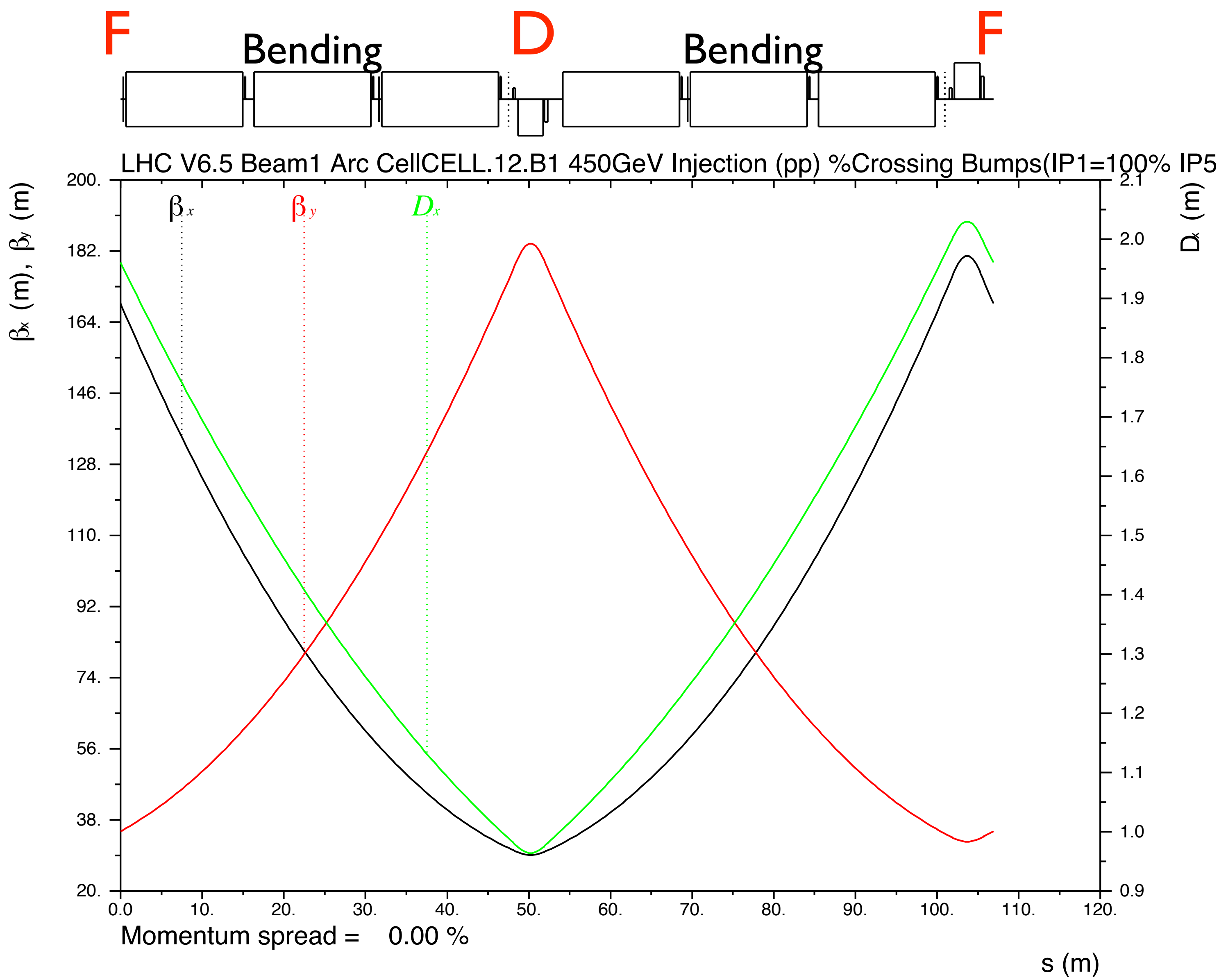
European Organization for Nuclear Research (CERN) -- LEP, LHC tunnel



General Layout

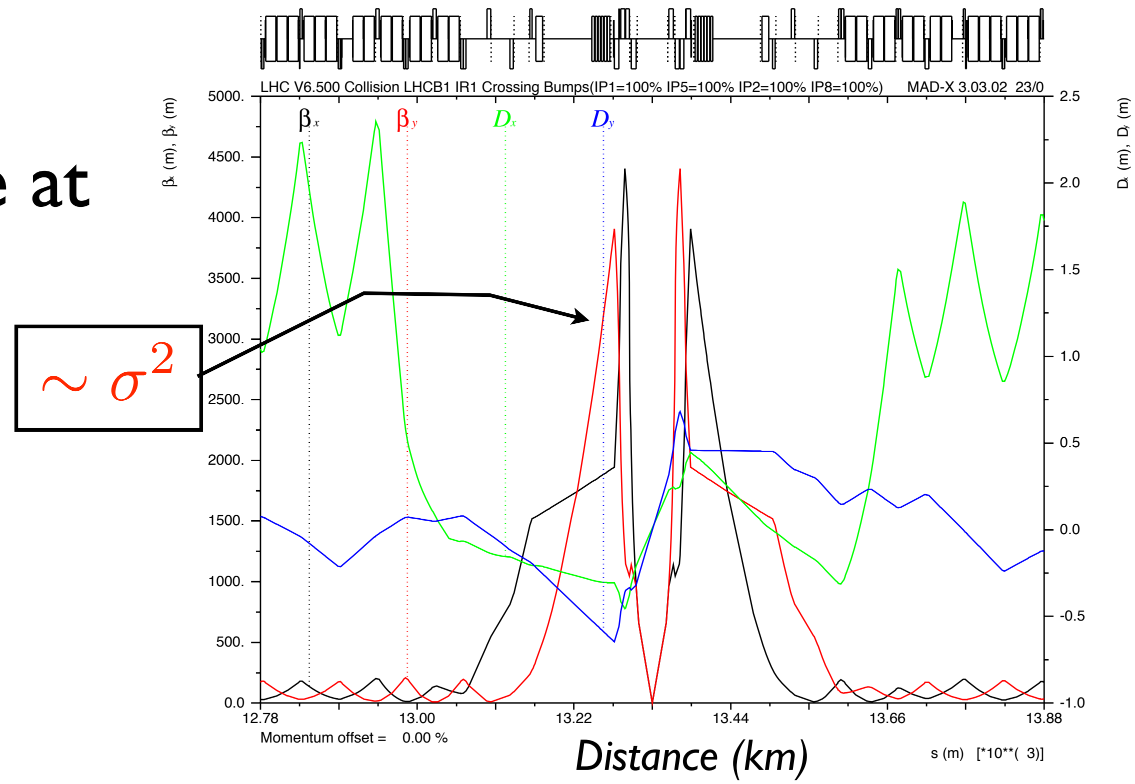


Standard Cell



Interaction Regions

- Beams collide in region much like at Tevatron, RHIC...
  - asymmetric triplet magnets focus to small spot
  - zero momentum dispersion
  - optics adjusted ("squeeze") once at final energy



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